LA-UR-22-20590

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Title: Basic Radiation Theory and Protection

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Intended for: Training slides for the Stabilization Program

Issued: 2022-01-24

Los Alamos
NATIONAL LABORATORY

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NNSA NA-84

Basic Radiation Theory and Protection

Lesson Objectives

1. Define the key terminology and concepts regarding radiation and radiation safety
2. Identify the types of radiation
3. Identify sources of naturally occurring radiation
4. Identify the consequences of various radiation exposures to the human body
5. Identify the regulatory limits of radiation for humans
6. Explain the three approaches to radiation protection

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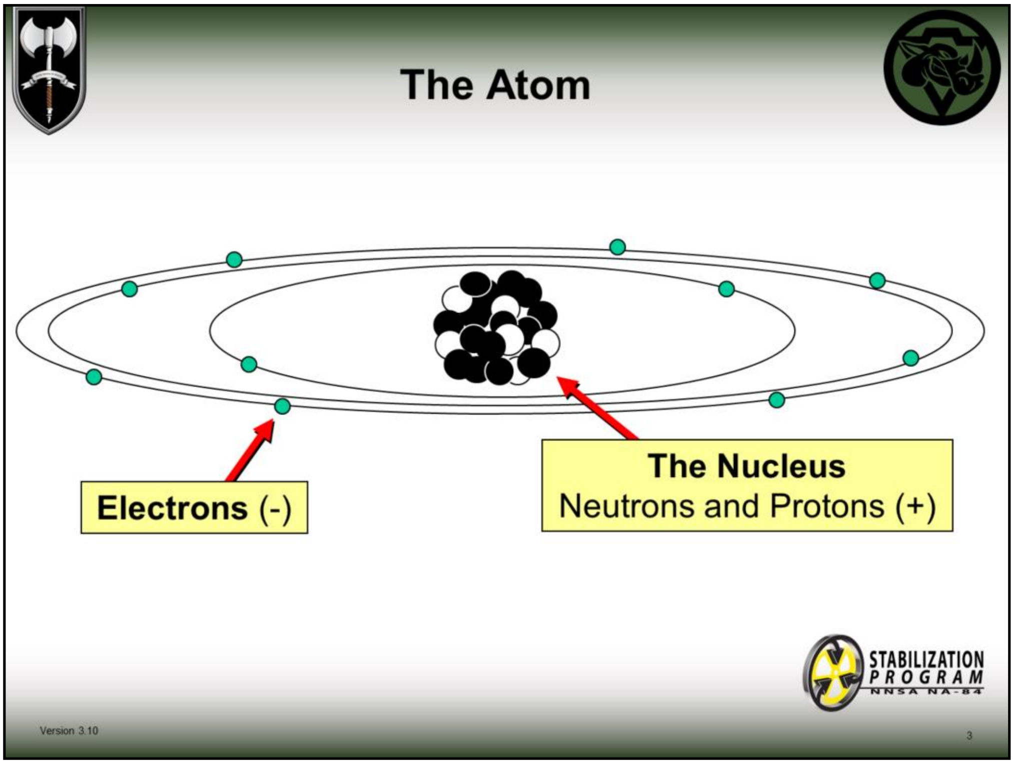

<u>For the Lesson Plan. Some of this (and the other slide notes) can be put into the Student Guide as supplement to the slide information</u>

•A typical model of the atom is called the Bohr Model, in honor of Niels Bohr who proposed the structure in 1913. The Bohr atom consists of a central nucleus composed of neutrons and protons, which is surrounded by electrons which “orbit” around the nucleus.

•Protons carry a positive charge of one and have a mass of about 1 atomic mass unit or amu (1 amu =$1.7e10^{-27}$ kg, a very, very small number). Neutrons are electrically “neutral” and also have a mass of about 1 amu. In contrast electron carry a negative charge and have mass of only 0.00055 amu.

•Neutrons make up the remaining mass of the nucleus and provide a means to “glue” the protons in place. Without neutrons, the nucleus would split apart because the positive protons would repel each other.

Isotopes

- *Same* element (# of protons)
- *Different* # of neutrons

Isotope	Protons	Neutrons	½ Life	Gamma-ray Signature
Cobalt-59	**27**	**32**	**Stable**	**Stable**
Cobalt-54	27	27	1.46 min.	1.4 and 1.1 MeV
Cobalt-60	27	33	5.3 years	1.3 and 1.2 MeV

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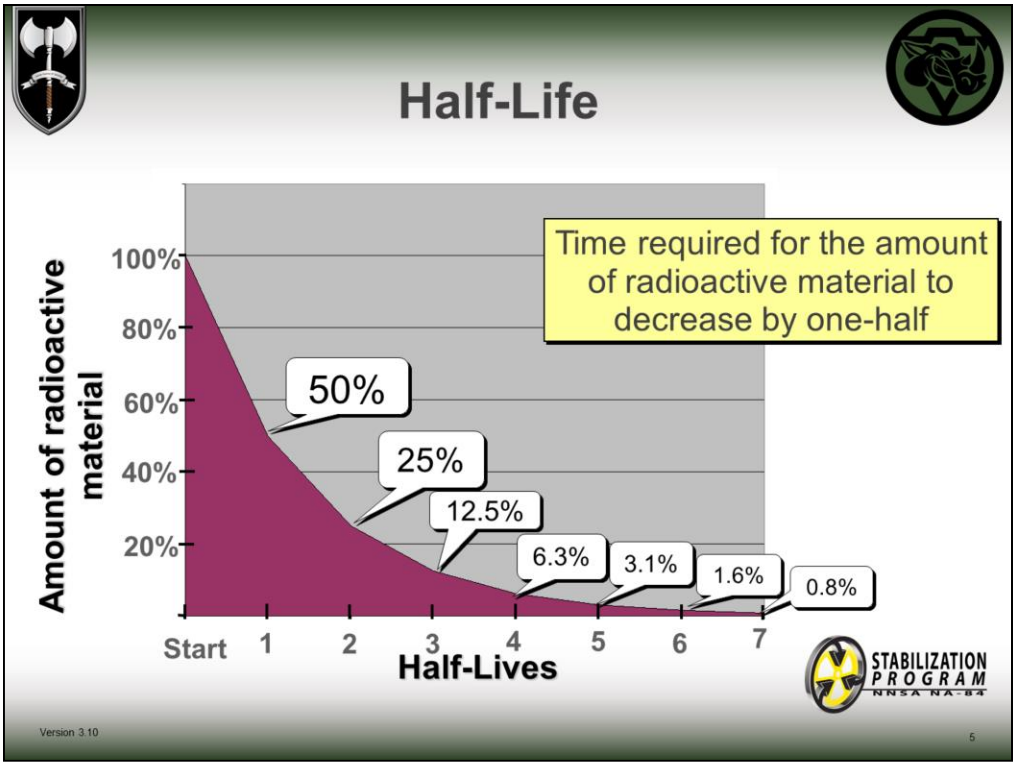
Elements can have nuclei with different numbers of neutrons in them. Atoms of the same element which vary in neutron number are called isotopes. Some elements have many stable isotopes (tin has 10), while others have only one or two. We express isotopes with the nomenclature Neon-20 or $^{20}_{10}N$, with twenty representing the total number of neutrons and protons in the atom, often referred to as A, and 10 representing the number of protons (Z).



Examples of half-lives of various radioactive materials—

Uranium-238 (most common U isotope found in nature)
4.5 billion years

Uranium-235 (fissile material)
700 million years

Plutonium-238 (often used as a heat/electrical source)
87.7 years

Plutonium-239 (fissile material)
24,100 years

Cesium-137 **30 years**

Technetium-99
6.02 hours

Cookie Problem

- One cookie with 1 mg Co-54
  - Half-life 1.5 minutes
- One cookie with 1 mg Co-60
  - Half-life 5.2 years
- Eat one, throw the other away
- WHATAYA DO?

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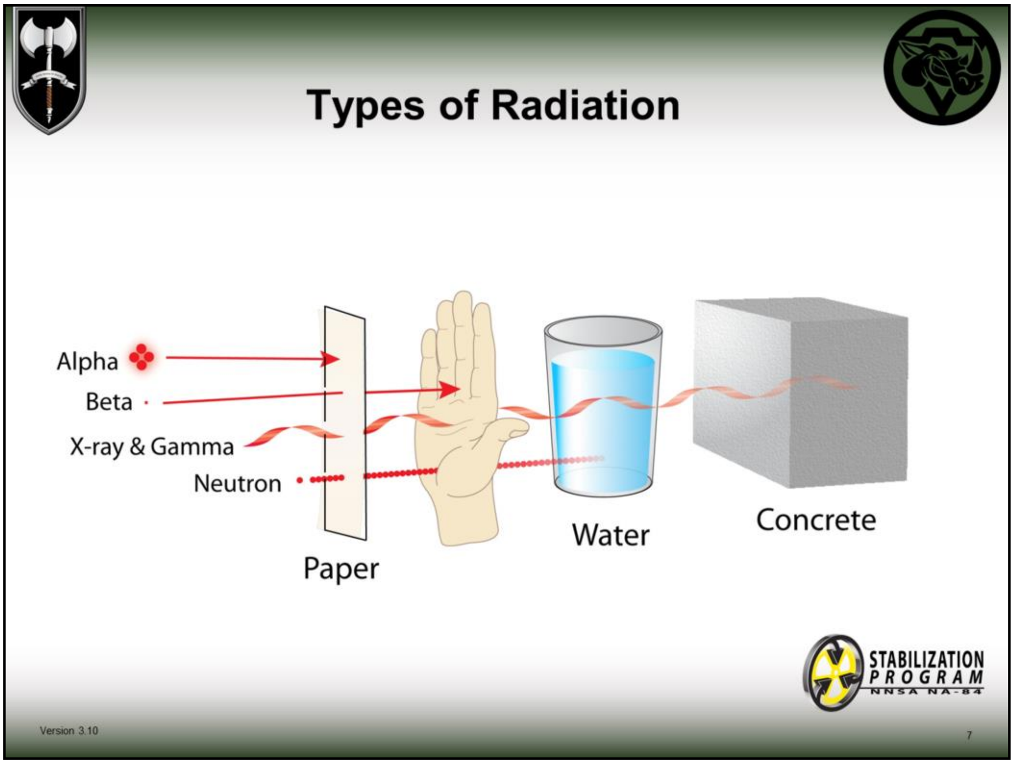
CHANGE NOTES:

1 mg of Co-54 will dump all its energy into your body long before it can be eliminated through natural digestive processes.

1 mg of Co-60 will be eliminated by the body before giving off most of its dose.



For SG (and LP)

•The most common types of radiation are alpha particles, beta particles, gamma and x-rays, and neutrons.

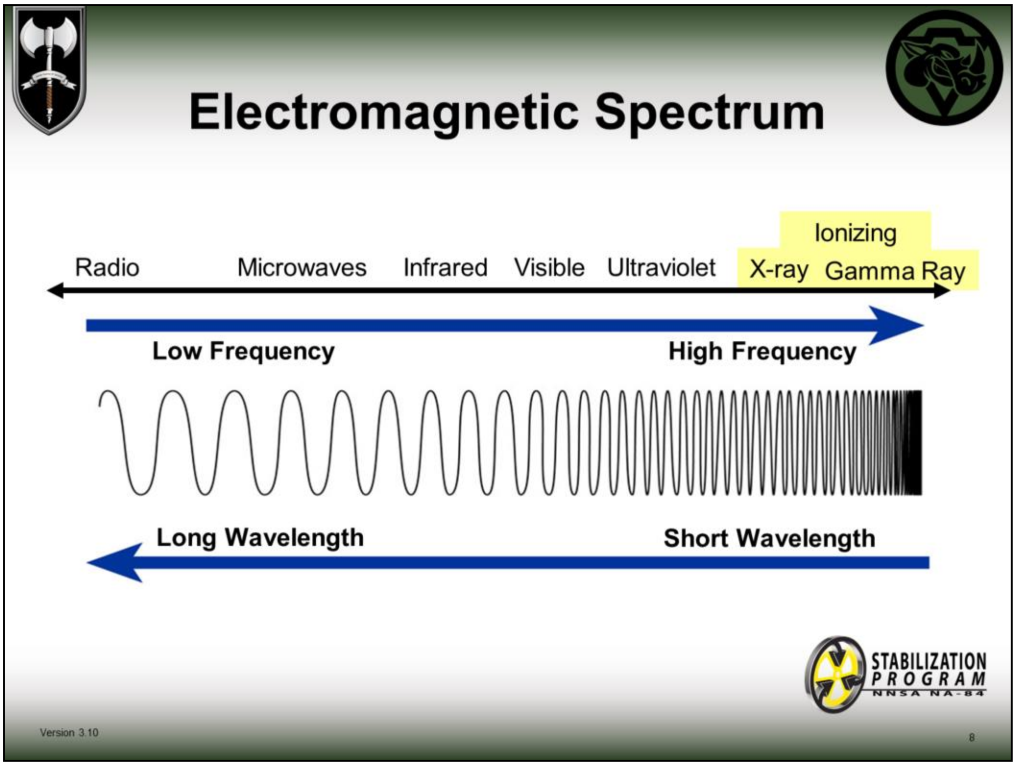
•Alpha particles are heavy and doubly charged which cause them to lose their energy very quickly in matter. They can be shielded by a sheet of paper or the surface layer of our skin. Alpha particles are only considered hazardous to a person's health if an alpha emitting material is ingested or inhaled.

•Beta and positron particles are much smaller and only have one charge, which cause them to interact more slowly with material. They are effectively shielded by thin layers of metal or plastic and are again only considered hazardous if a beta emitter is ingested or inhaled.

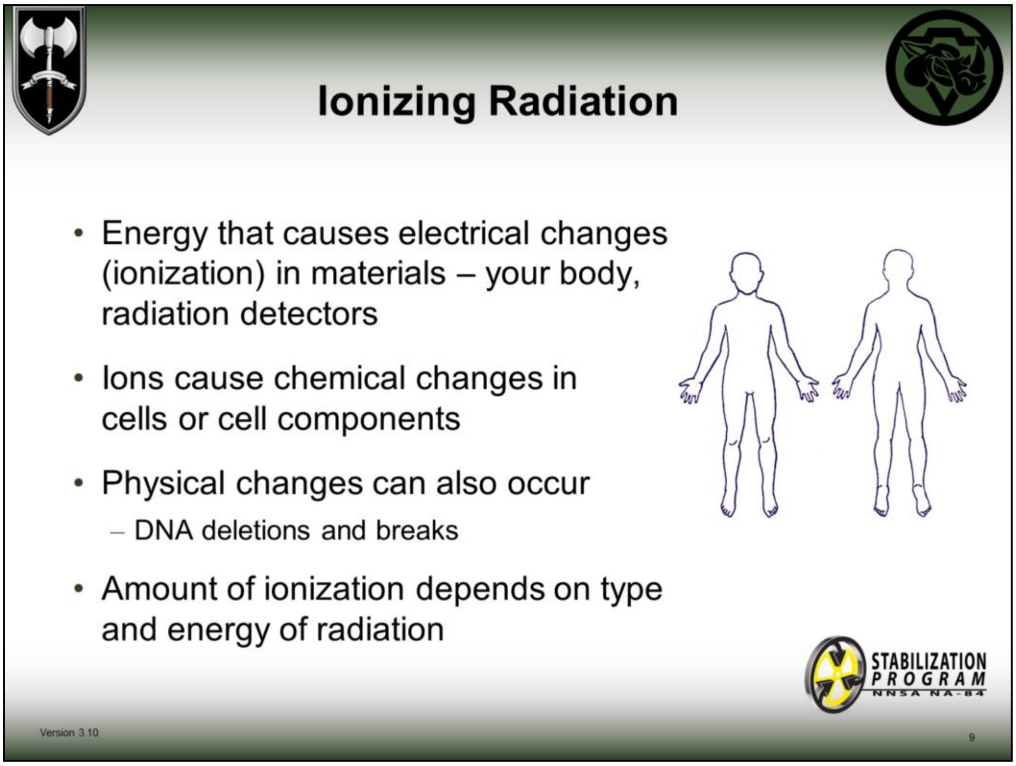
•Gamma emitters are associated with alpha, beta, and positron decay. X-Rays are produced either when electrons change orbits within an atom, or electrons from an external source are deflected around the nucleus of an atom. Both are forms of high energy electromagnetic radiation which interact lightly with matter. X-rays and gamma rays are best shielded by thick layers of lead or other dense material and are hazardous to people when they are external to the body.

•Neutrons are neutral particles with approximately the same mass as a proton.

Because they are neutral they react only weakly with material. They are an external hazard best shielded by **hydrogen rich materials such as water, concrete and paraffin plastic.**



FYI: Students will be exposed to the electromagnetic spectrum in the RF Fundamentals lesson.



Ions are electrically charged atoms. Atoms gain a charge by the subtraction or addition of electrons; the loss of electrons (possibly by exposure to ionizing radiation) makes an atom positively charged, the addition of electrons makes an atom negatively charged.

Background Radiation

- Cosmic
  - Varies with altitude
  - Varies with latitude
  - Sunspot activity
- Terrestrial
  - Varies with location
    - Soil type, formation
- Total of ~ 1 mrem/day (10 μSv/day)
  - At sea level

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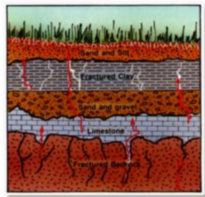
Terrestrial Sources

- Uranium in soil
  - Decays to radon gas
    - Majority of radiation exposure (55%) for most people
- Potassium-40 (K^{40})
  - Most predominant nuclide in foods
- Thorium-232
  - Common in tile glazes



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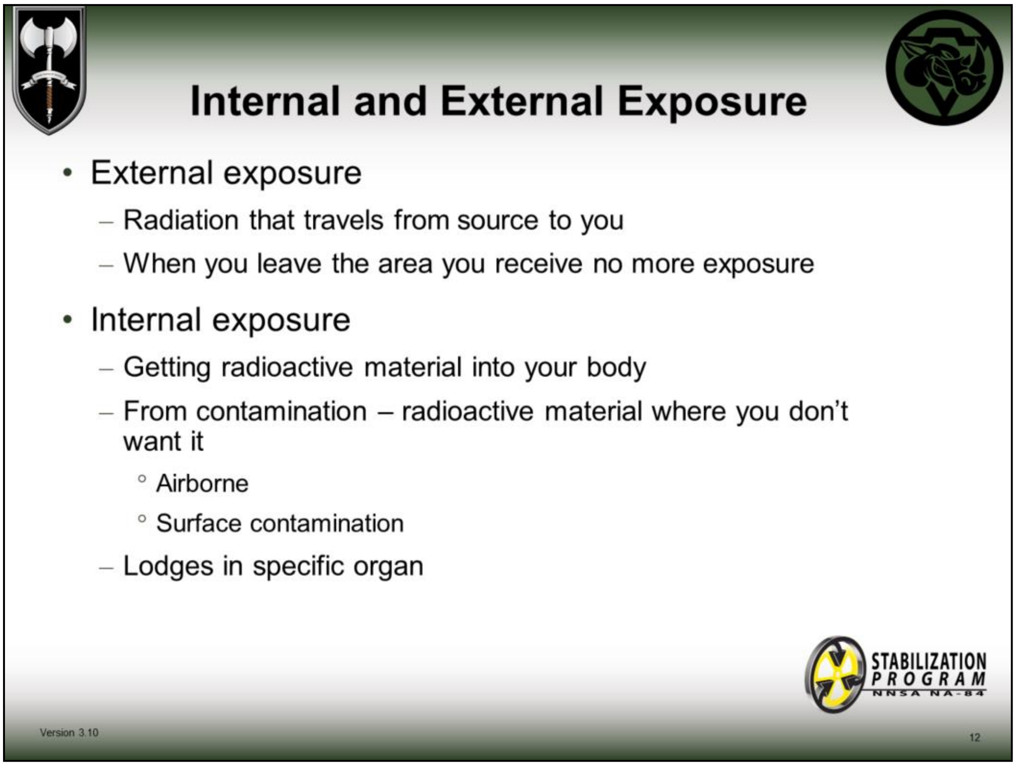
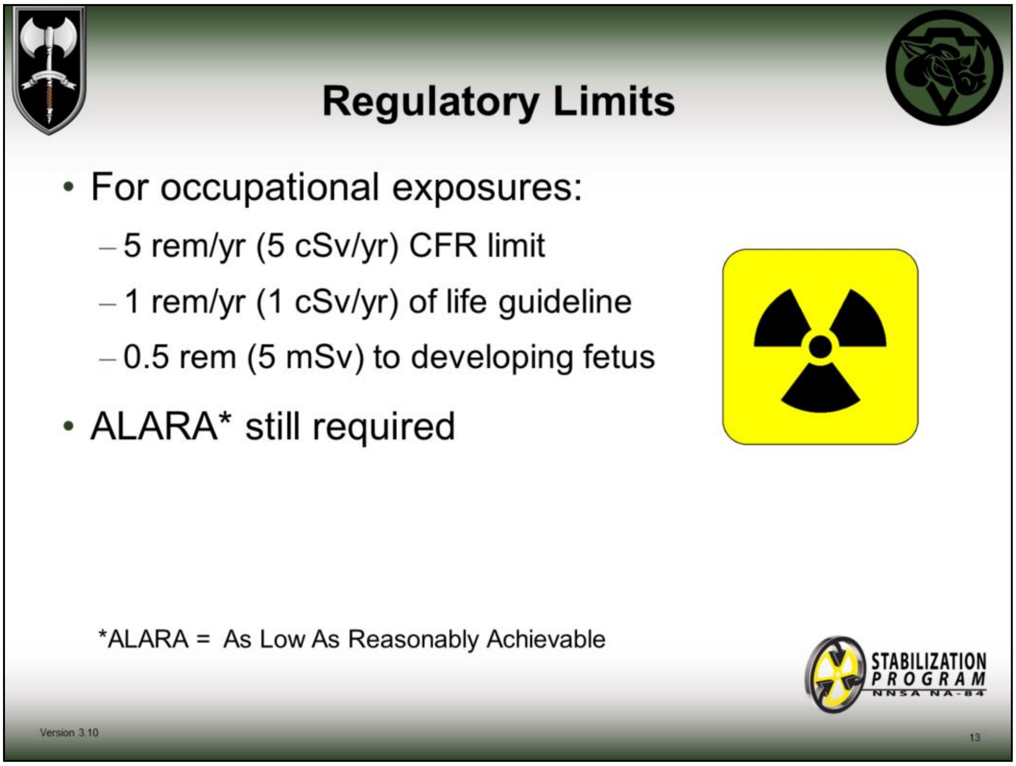


"An internally deposited radioactive element may concentrate in, and thus irradiate, certain organs more than others. Radioiodine, for example, collects in the thyroid gland, whereas radium and strontium accumulate chiefly in the bones." -- https://www.britannica.com/science/radiation/Accumulation-in-critical-organs



For SG:

As Low as Reasonably Achievable = ALARA

Overexposure Consequences

Dose (rad / Gy)	Organ System	Syndrome
15-50 / 0.15-0.5	Blood - microscopic	no symptoms, changes in blood cell counts
100-500 / 1-5	hematopoietic (blood)	transitory nausea, vomiting, diarrhea, then increased susceptibility to infection, death in 3-6 weeks
500-2000 / 5-20	gastrointestinal (GI)	vomiting, loss of appetite, weight loss, reduced leukocytes, death in 5 days
>2000 / 20	central nervous system (CNS)	neurological, behavioral, psychological changes, tremors, convulsions, coma, death in 24-48 hours

400-450 rem (4-4.5 Sv) exposure
Death for 50% of exposed population within 30 days

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Dose Measurement

- TLDs (Thermoluminescent Dosimeters)
  - Commercial aircraft baggage, carry-on
  - Retrospective
- Pencil Dosimeters
  - Rugged, simple
- Electronic Dosimeters
  - Alarms
    - Rate, total
- Bioassay

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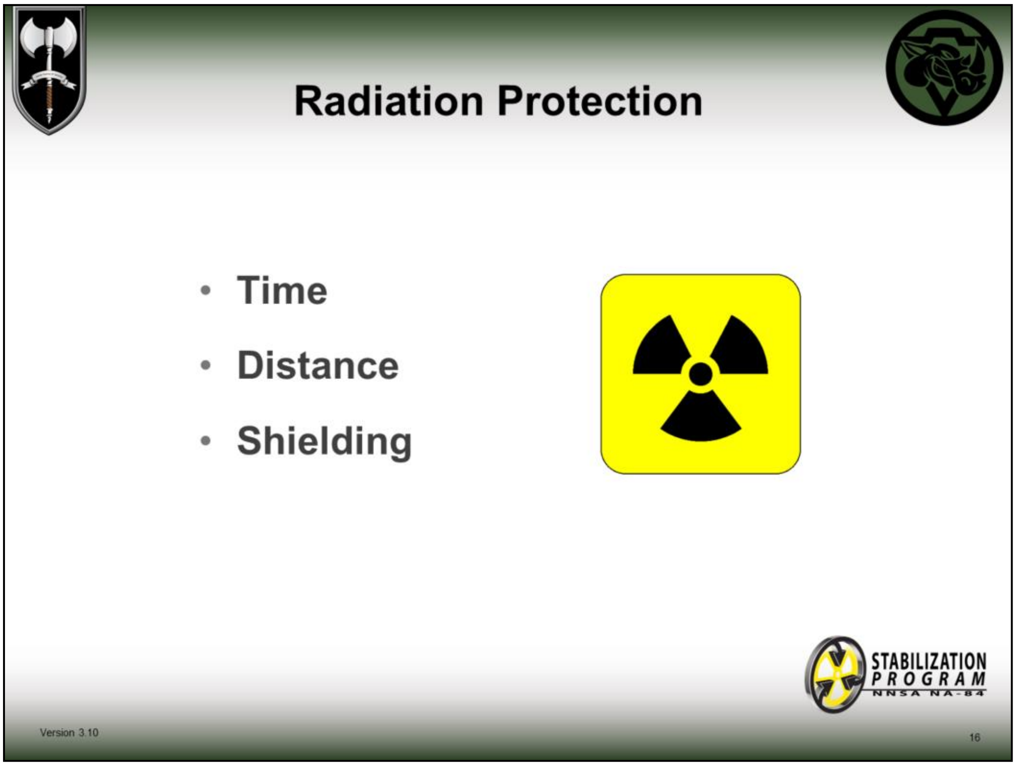
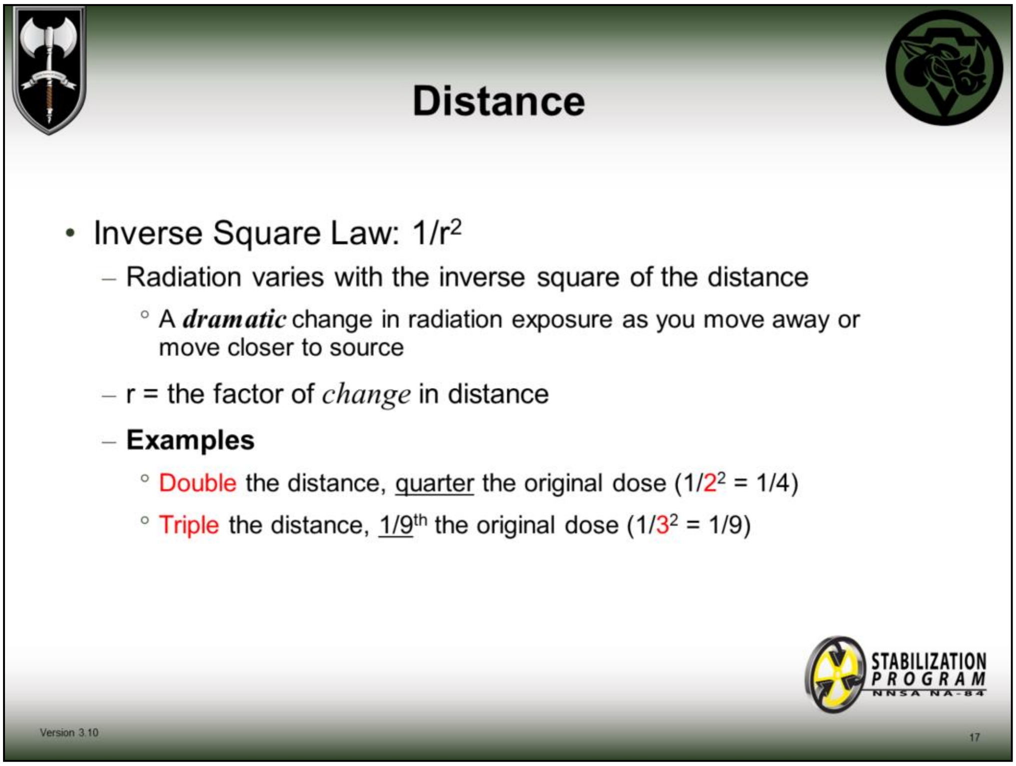


•Time
The amount radiation exposure received from a source is directly proportional to the amount of time spent in the field of radiation. Doubling the amount of time spent at a fixed point in a radiation field will double the absorbed dose

•Distance
Distance is another way to affect the absorbed dose. Moving further away from the radiation source will reduce the absorbed dose. In fact, the absorbed dose at a given distance can be calculated using the “inverse square law.” (see the next slide)

•Shielding
Various materials placed between you and the radiation source is the third method for reducing the amount of radiation exposure. The effectiveness of the material depends on the type of radiation (e.g., alpha, beta, gamma), what the material is made of and the density of that material.



Formula for inverse square law (to find dose rate at a new distance):

(Distance 1/Distance 2)^2 x Dose Rate 1 = Dose Rate 2

What is dose rate if I am getting 100 mR/hour at 10 feet from source and move to 15 feet from source?

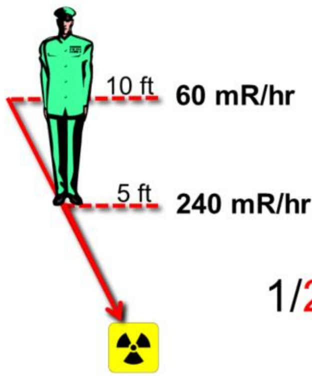
- Divide 10 (Distance 1) by 15 (Distance 2) = 0.67 (rounded). Square 0.67 = 0.449 (rounded). Multiply that by 100 mR/hour (Dose Rate 1) = 44.9 mR/hour (Dose Rate 2) at 15 feet.

What is dose rate if I am getting 44.9 mR/hour at 15 feet from source and move in to 10 feet from source?

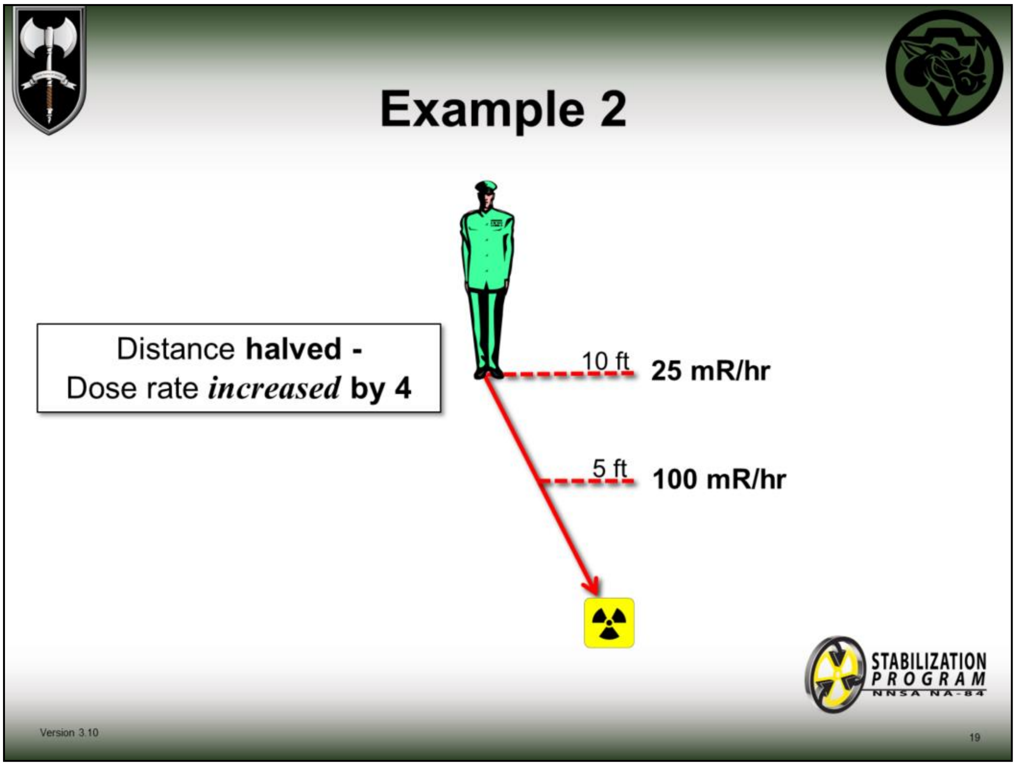
- Divide 15 (Distance 1) by 10 (Distance 2) = 1.5. Square 1.5 = 2.25. Multiply 2.25 by 44.9 mR/hour (Dose Rate 1) = 101.025 mR/hour (Dose Rate 2) at 10 feet.
- Does not equal 100 mR/hour because of errors introduced by rounding numbers in first example.

Example 1

Distance **doubled** -
Dose rate **reduced to 1/4**
of original



$1/2^2 = 1/4$


Example 2
Distance **halved** -
Dose rate ***increased* by 4**
10 ft
25 mR/hr
5 ft
100 mR/hr
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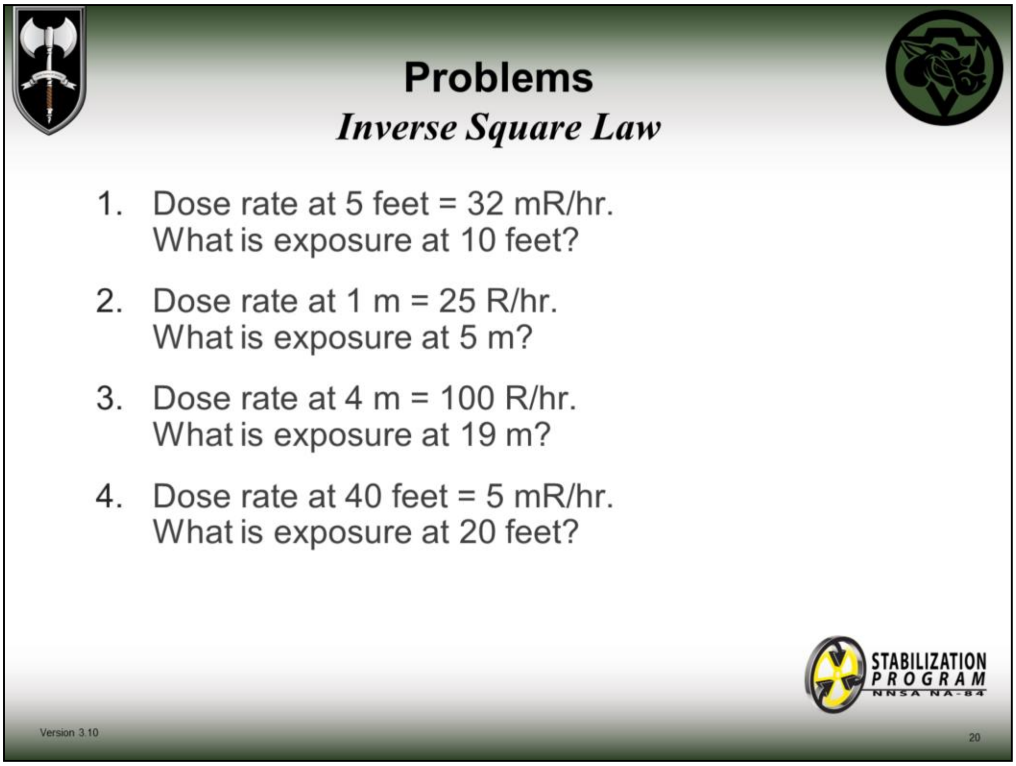


Do the first one as a class and then have them work in pairs to do the remaining three.

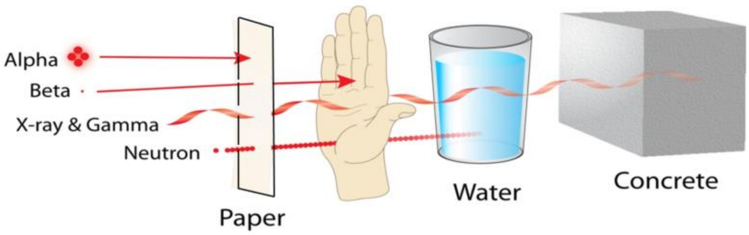
Answers: **1.** 8 mR/hr **2**. 125 mR/hr **3**. ~20 mR/hr **4**. 20 mR/hr

Shielding

- Increase amount of material, decrease exposure
- Effectiveness depends on energy of radiation, type of material, and density of material

Shielding (cont'd)

- Shield material depends on type of radiation
  - Neutron radiation vs. gamma-ray radiation



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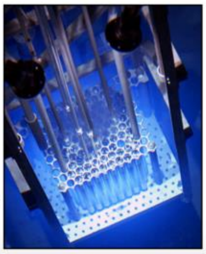
Shielding (cont'd)
Neutrons

- Neutrons collide with single protons to lose energy
  - Hydrogen has single proton
- Hydrogenous materials work well
  - H_20, hydrocarbons (oil, polyethylene) to *thermalize*
  - Then absorb (although H will capture some)



Nuclear fuel rods in water

Polyethylene

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Shielding (cont'd)
Gamma-rays

- Gamma rays interact directly with electrons
- Dense materials have more electrons/unit volume
  - Concrete
  - Lead

Concrete shielding vault

Lead shielding

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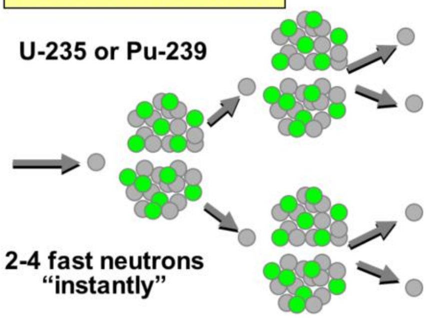
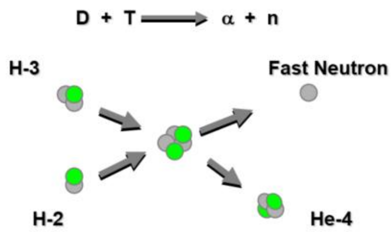
Fission / Fusion

Nuclear Fission



- Radioactive fission products
- Fission energy release: 18 kT/kg

Thermonuclear Fusion



- Kinetic energy overcomes repulsion
- Light nuclei fuse
- Fusion energy release: 70 kT/kg

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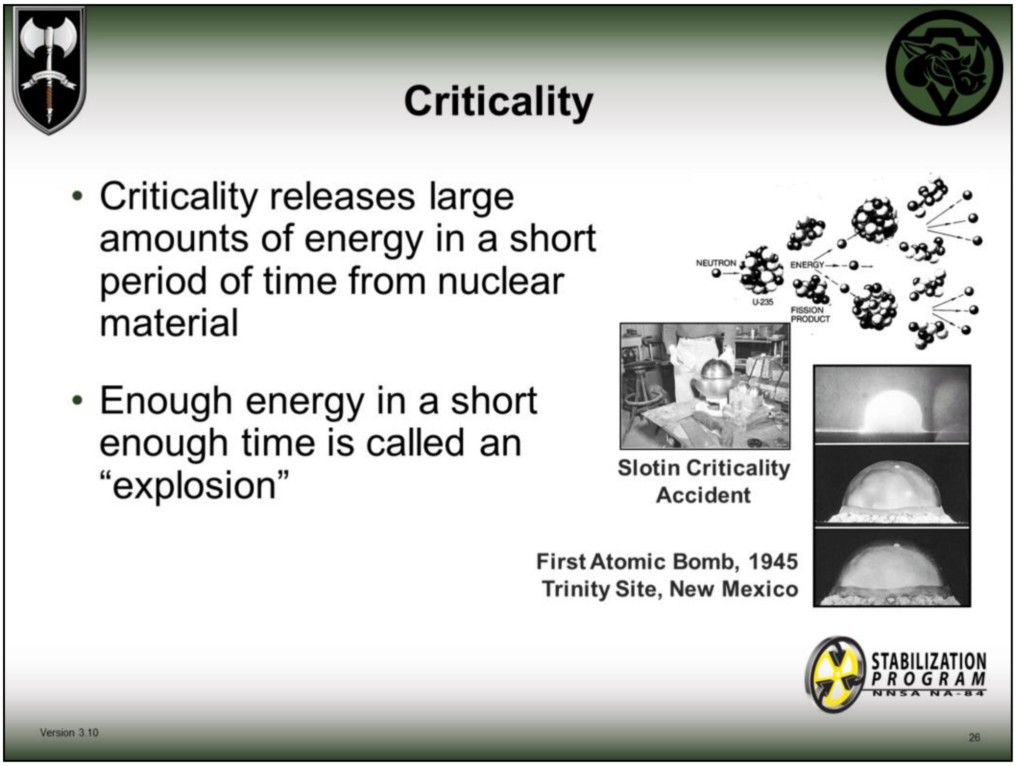

(ADD INSTRUCTOR NOTE)

References for Slotin Incident

https://www.newyorker.com/tech/annals-of-technology/demon-core-the-strange-death-of-louis-slotin

https://www.atomicheritage.org/history/atomic-accidents

Criticality (cont'd)

- If nuclear materials are configured more slowly, a criticality accident can occur
  - Fatal to nearby (<10 ft, 3.1 m) people
  - No mushroom cloud
  - No warning
  - Can be prevented

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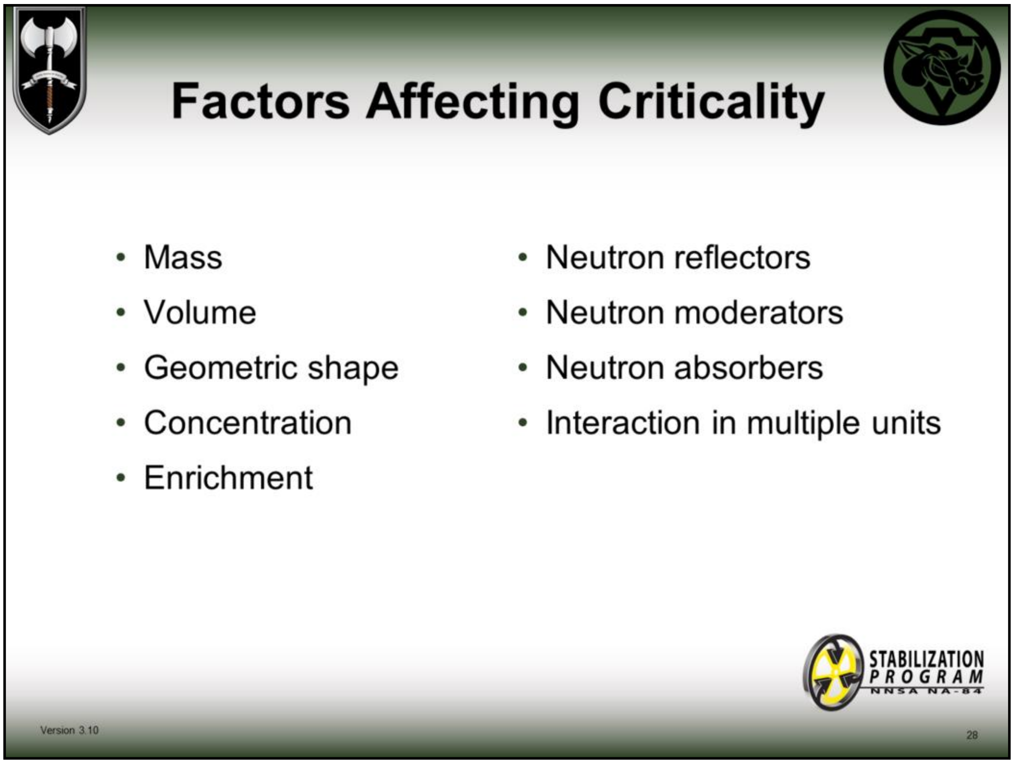

Each of these factors, individually or collectively, can influence whether neutrons are reflected back into the material or absorbed on their way out and what affect that reflection/absorption will have in terms of criticality.

Summary

- Isotope
  - Same element, different # of neutrons
- Alpha and beta radiation
  - Easily shielded; hazardous only if ingested
- X-rays and gamma-rays
  - Best shielded by dense materials
  - Hazardous if exposed to human tissue
- Neutrons
  - Best shielded by hydrogen-rich materials (e.g., water)
  - Hazardous if exposed to human tissue

Summary (cont'd)

- Ionizing radiation
  - Causes electrical changes in materials
- Occupational exposure to radiation (CFR limit)
  - 5 rem/yr (5 cSv/yr)
- Radiation exposure amounts
  - ~400 rems (4 Sv) – possible death
- Half-life
  - Time required for radioactive material to decrease by ½
- Radiation protection
  - Time – Distance – Shielding

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Summary (cont'd)

- Inverse square law ($1/r^2$)
  - Triple the distance, cut exposure to 1/9th
- Fission
  - Nuclei split, releases energy
  - U-235 and Pu-239
- Fusion
  - Light nuclei fuse together, releases energy
  - Hydrogen bomb – more difficult to make
- Criticality
  - Release of large amounts of energy in short amount of time
  - Several factors affect criticality

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